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EVN observations of an OH maser burst in OH17.7−2.0

M. Szymczak* **and A. Bartkiewicz**
Toruń Centre for Astronomy, Nicolaus Copernicus University, Poland
E-mail: msz@astro.uni.torun.pl, annan@astro.uni.torun.pl

E. Gérard
Observatoire de Paris, France
E-mail: Eric.Gerard@obspm.fr

We have observed the OH 1612-MHz maser emission towards the proto-planetary nebula candidate OH17.7−2.0 that underwent a very strong and unusual outburst in 2003. Phase-referencing data were obtained with the EVN in order to localize the outburst and to examine its possible causes. The majority of the emission comes from an incomplete spherical shell with inner and outer radii of 220 and 850 mas, respectively. There is a strong evidence for maser components that arise due to the interaction of a jet-like post-AGB outflow with the remnant outer AGB shell. The most prominent signature of such an interaction is the strongly bursting polarized emission near 73.3 km s^{-1} coming from two unresolved components of brightness temperature up to 10^{11} K located at the edge of the biconal region 2500 AU from the central star. It is remarkable that this OH biconal region is well-aligned with the polar outflow inferred from the near-infrared image.

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*Speaker.

1. Background and motivation

There are several lines of evidence that OH17.7−2.0 is an oxygen-rich post-AGB object. Its central star has a spectral type earlier than ~K5 with an effective temperature ~4000 − 10000 K ([6]). This is a dusty object with far-infrared colours consistent with a detached shell and mass-loss rate of $\sim 4 \times 10^{-5} M_{\odot} yr^{-1}$ ([9]). At 2.2 μm it appears as a prolate spheroid with the polar axis at a position angle of 20° ([1]). Non-variability or only slight variations at near-infrared wavelengths ([6]), small amplitude OH flux variations at 1612 MHz ([4]), disappearance of the H_2O maser ([2]) and non-detection of SiO masers ([7]) are consistent with a post-AGB status of OH17.7−2.0.

In 2003, the OH 1612-MHz maser line profile underwent a very unusual change; the intensity of the red-shifted emission at velocity ~73 km s^{-1} increased nearly threefold over a period of ~430 days ([8]). The flaring feature exhibits strong (up to 80%) circular polarization and considerable (~15%) linear polarization. It is remarkable that adjacent red-shifted features do not show variations within an absolute flux density uncertainty less than 10%. Furthermore, the entire blue-shifted part of the 1612-MHz spectrum does not show any variations either. Finally, no changes were detected in the integrated flux densities of the 1665 and 1667-MHz maser lines ([8]).

The outburst event in OH17.7−2.0 is spectacular and unique when compared to flare phenomena in circumstellar OH masers reported in the literature. Almost all eruptive changes in OH maser emission observed so far took place in Mira-type variables and are characterized by global changes with time scales of months and years in the OH profiles of the 1612, 1665 and 1667-MHz transitions when present ([5], [3]), usually weakly associated with changes in the optical and/or infrared.

In this paper, we report the preliminary results of follow-up VLBI observations taken in order to localize the burst in the shell and to determine the properties of the active regions. This should allow us to constrain possible causes of the outburst ([8]) and to understand the evolutionary status of the central star.

2. Observations and reduction

The OH 1612-MHz observations were carried out on 2005 March 3 using eight EVN telescopes: Cambridge, Effelsberg, Hartebeesthoek, Jodrell Bank, Medicina, Onsala and Toruń. The observations consisted of six 38-min. scans on the target interleaved with 6-min. scans on the phase-calibrator source J1733−1304. One-hour scan of the continuum source J2253+1608 was also made for the purpose of bandpass and amplitude calibration. Dual circular polarization was recorded using the MarkV system with a spectral bandwidth of 0.5 MHz. For OH17.7−2.0, this translates to LSR velocities from 15 to 108 km s^{-1}. The data were correlated with the JIVE correlator using 1024 channels, yielding a spectral resolution of 0.09 km s^{-1}. Correlated data were calibrated and reduced using AIPS package, following the standard procedures for spectral-line VLBI observations. The resulting synthesized beam size was 64×20 mas at a position angle 9°. An area of 2×2 arcsec^2 was searched for maser emission above 5σ limit over the entire band. For single circular polarization, the rms noise in the final emission-free channel maps was ~9 mJy. The relative positions of the maser components were determined with 0.5 mas accuracy.

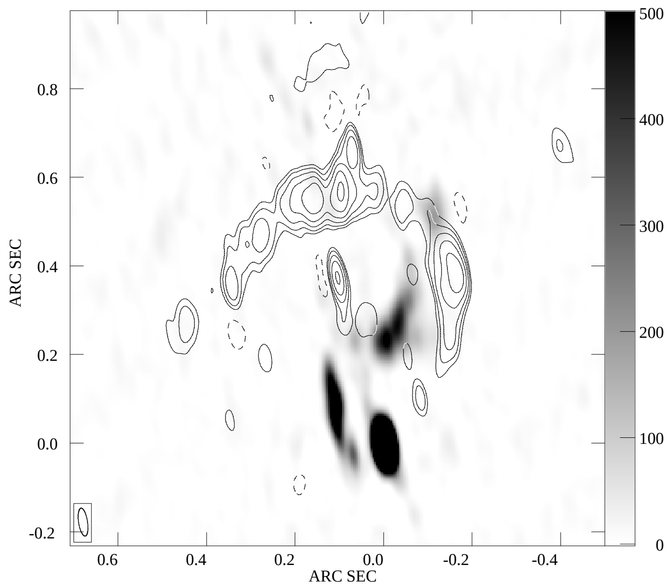

Figure 1: Integrated intensity map of the OH 1612-MHz maser emission of OH17.7−2.0 for left-hand circular (LHC) polarization. The contours plotted at intervals of (-1, 1, 2, 4, 8, 16)×20 mJy beam^{-1} m s^{-1} show the blue-shifted emission (V <61.6 km s^{-1}). The red-shifted emission (V >61.6 km s^{-1}) is shown in grey that scales from 0 to 500 mJy beam^{-1} m s^{-1}. Note that, for better presentation, the grey scale is cut at 500 mJy beam^{-1} m s^{-1} level and the peak intensity of the southern unresolved component is 9931 mJy beam^{-1} m s^{-1}. The map origin is at RA(J2000)=18^{h}30^{m}30$^{s}_{.}$695, Dec(J2000)=−14°28′56.″82. The ellipse in the bottom left corner of the map represents the restoring beam.

3. Results

OH 1612-MHz maser emission was detected at velocities between 47.9 and 75.0 km s^{-1}; this is a slightly narrower range than that reported in MERLIN observations ([1]).

Fig. 1 shows the LHC map of line emission integrated over all channels. Most of the blue-shifted emission originates from a ring-like structure which resembles a symmetric shell of about 510 mas diameter. No emission is seen from the S and the SE parts of the shell. Compact and unresolved emission in the velocity range of 48.6−49.6 km s^{-1} is found at a position which coincides, within the synthesized beam, with the position of the central star inferred from the model of expanding spherical shell. Thus, this compact emission is very likely the amplified stellar image. Weak and diffuse maser components at blue-shifted velocities higher than 48.5 km s^{-1} are seen ∼380 mas to the SE and ∼600 mas to the NW of that compact emission (the amplified stellar image), at a position angle of ∼160°. The red-shifted diffuse emission is also detected at roughly the same position angle but is weakly visible in Fig. 1 due to dynamic range limitations. Weak and scattered emission likely comes from an equatorial region. The red-shifted emission is dominated by two very strong (>150 Jy beam^{-1}) unresolved components at velocities ∼73 km s^{-1} and at a projected distance of ∼400 mas south of the central star. The brightness temperature of these bursting components is up to 10^{11} K. The rest of the red-shifted emission follows a ring-like distribution with the SW part clearly seen. Clearly, there is a lack of red-shifted emission from the northern side of the shell.

4. Interpretation

In general, the masers are located within a remnant spherical shell (Fig. 2). However, there is evidence for several major departures from the simple shell model. (1) There is an offset of ∼300 mas between the two emission peaks at extreme velocities along an axis at position angle of 8.4°. (2) Along the same position angle, a biconal region can be seen; the emission appears to come from the sides of the cones as projected on the sky and likely represents the interaction of a faster post-AGB wind or jet with the outer AGB wind. In this case, the boundary appears to be thin and tangential emission may dominate. The opening angle of the cone is less than 15° while the inclination angle between the equatorial plane and the line of sight is ∼ 30°. The red-shifted bubble is at projected distance of ∼ 400 mas. (3) Low-brightness emission at middle radial velocities scattered along a plane roughly orthogonal to the axis of the cones is likely due to the emission from the denser equatorial region or torus-like structure. Such a region can be produced during a period of enhanced mass loss at the end of the AGB phase. The OH maser emission from this region, as predicted by a spherical shell model, should be weak due to short amplification path length.

It is remarkable that the position angle of the axis of biconal region seen in the OH 1612-MHz maser distribution (∼ 10°) is quite consistent with the position angle of the major axis of the infrared nebulosity of size 2.5 arcsec (20°, [1]). This confirms that OH17.7−2.0 recently started a bipolar outflow.

The position-velocity diagram (Fig. 3) implies that a spherical velocity field for the bulk of the 1612-MHz emission, in the first instance, satisfactorily fits all the data. The position of the central star is $\Delta\alpha$=74 mas, $\Delta\delta$=396 mas relative to the map origin (Fig. 1) and coincides within the beam with the position of the compact blue-shifted emission which is interpreted as the amplified stellar image. The best-fitted systemic and expansion velocities are 61.6 km s^{-1} and 13.8 km s^{-1}, respectively. The inner radius is 220 mas while the outer radius is up to 850 mas. Although the envelope is sparsely filled with the maser components, Fig. 3 shows evidence for multiple shells which may result from periodic enhancements of mass loss rate within a range of 300-800 years, for the assumed distance of 3.4 kpc. It appears that the maser outburst occurred in a shell of radius of 740 mas, i.e., 2500 AU from the central star. For the first time, the present data provide evidence that OH17.7−2.0 has a bipolar morphology of the 1612-MHz maser emission and the active region is confined to the surface of bubble. We argue that one of most plausible causes of the burst is an interaction of a jet-like outflow with the remnant outer AGB shell. If the disappearance of the H_2O maser in 1990 ([2]) is casually related to the 1612-MHz OH outburst in 2003 and assuming that the H_2O maser arose in an inner AGB shell (∼50 AU), the speed of the jet-like outflow should be ∼800 km s^{-1}. The presence of such outflows is documented in many proto-planetary nebulae, but their effect on the onset of the OH maser emission is not well understood ([8]). Our data suggest that the outburst emerges from a narrow interface between the surface of the bubble and

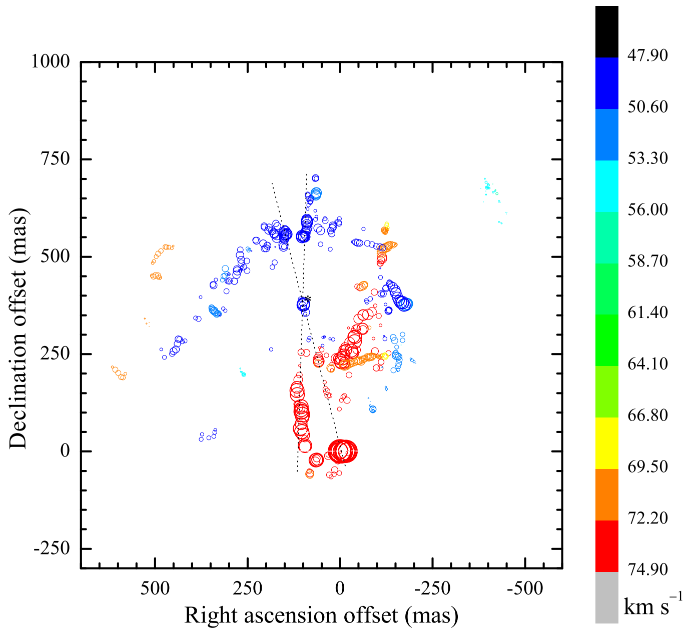

Figure 2: The overall distribution of all maser components brighter than 10σ (>100 mJy beam^{-1}). The origin of diagram is the position of the brightest component. The size of the symbols is proportional to the logarithm of brightness. The colour corresponds to the velocity scale shown by a vertical bar. The dashed lines outline the polar cavities where the maser emission is quenched while it is present at the biconal surface.

dense clumps of the detached AGB shell where the magnetic field must play a role in the maser amplification since only one sense of circular polarization is seen.

MERLIN observations of OH17.7−2.0 revealed the southern outlying components ([1]) which are interpreted as the result of the interaction of a fast post-AGB wind with the remnant outer AGB wind. In this scenario, the OH masers also trace the radial outflow away from the central star along the surface of the cones; the velocities of these maser components increase linearly with the distance from the star ([10]). The presence of such OH components was confirmed in some post-AGB objects with broad (>50 km s^{-1}) OH profiles ([10]). We failed to find a similar phenomenon in our target. This suggests that OH17.7−2.0 is in an early post-AGB evolution phase.

5. Concluding remarks

The most striking result from the first-epoch EVN observations is the identification of an active region where the 1612-MHz outburst occurred. This finding strongly constrains a suite of possible causes of the outburst ([8]). It appears that one of the most probable causes is the interaction of a jet-like outflow from the post-AGB star with dense clumps of the remnant outer AGB shell. This confirms that OH17.7−2.0 is in a transitional, short-lasting phase from AGB to PN. Multi-epoch VLBI observations would allow us to trace the changes in the structure of OH maser emission and to explain a possible role of the magnetic field in the shaping of the bipolar outflow. It seems that this target is ideal for optical and infrared observations in order to obtain a complete picture of the changes occurring in the whole envelope.

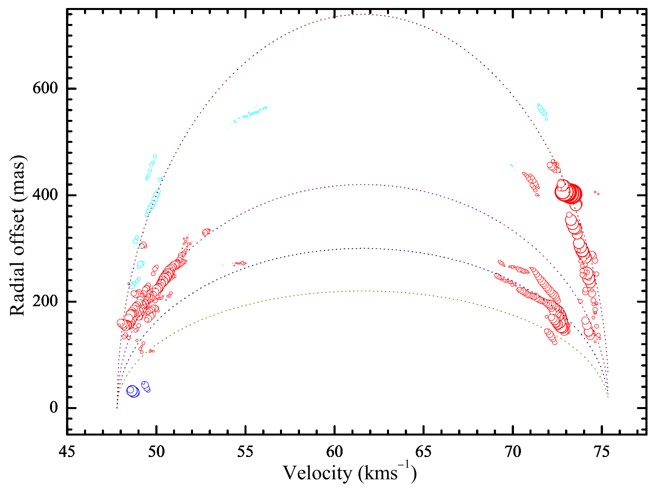

Figure 3: Radial offset of the maser components from the best fitted stellar position as a function of the radial velocity. The circle size is proportional to the logarithm of the component brightness. Colours distinguish the components from the shells (red), the equatorial region (cyan) and amplification of stellar photons (blue). The dashed curves correspond to the models of spherical shells of radii 220, 300, 420 and 740 mas assuming a constant outflow velocity of 13.8 km s^{-1}.

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